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The experimental performance of an unglazed PV-thermal collector with a fully wetted absorber

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Abstract

In general, there are two types of PVT collector, glazed and unglazed, depending on the existence of glass in front of the PV module. On the other hand, water-type PVT collectors can be classified into two types according to absorber type: the sheet-and-tube absorber PVT collector and the fully wetted absorber PVT collector.
The aim of this study is to analyze the electrical and thermal performance of a water-type PVT collector with a fully wetted absorber. For this study, a prototype of an unglazed PVT collector with a fully wetted absorber was designed and built, and both the thermal and electrical performances of the prototype PVT collector were measured in outdoor conditions. A conventional mono-crystalline Si PV module was tested alongside the PVT collector in order to compare their electrical performance

Kewords: Unglazed photovoltaic-thermal collector; fully wetted absorber; conventional PV module; thermal efficiency; electrical efficiency

1. Introduction

The overall efficiency of a PV system, which has relatively lower efficiency among the renewable energy systems, depends on the efficiency of the solar cells and the PV module themselves. Today, in general, PV modules that are based on silicon wafer have an electricity efficiency of about 12~16% in standard test conditions (STC: solar spectrum of AM 1.5, irradiance of 1000W/㎡ and module temperature at 25℃). Furthermore, it is a concern that the efficiency of PV modules of a BIPV system can decrease due to the increase of the PV module temperature.

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The photovoltaic/thermal (PVT) concept offers an opportunity to increase the overall efficiency of a PV module through the use of the waste heat generated in the PV module. It is well known that PVT systems enhance the PV efficiency through a cooling effect. Moreover, this can be achieved by circulating a relatively cold fluid, water or air on the underside of the PV module.

A photovoltaic/thermal (PVT) collector is a combination of a photovoltaic module and a solar thermal collector, forming one device that converts solar energy into electricity and heat simultaneously [1]. The heat from PV modules can be removed in order to enhance the electrical performance of the PV module; this heat can be converted into useful thermal energy. As a result, PVT collectors can generate more solar energy per unit surface area than side by side photovoltaic modules and solar thermal collectors can [2].

In general, regarding water-type PVT collectors, two types can be distinguished. The first is the glazed PVT collector, which has the advantage of heat production, and the second is the unglazed PVT collector, which produces relatively less thermal energy but shows better electrical performance than the former type (Fig. 1).

Glazed PVT collectors are very similar in appearance to flat-plate solar thermal collectors, consisting of a PV-covered absorber in an insulated collector box with a glass cover. This glass-covered insulation leads to high thermal efficiency with some reduction of electrical efficiency due to solar radiation reflection and the increase in the PV module temperature caused by the glass cover. Unglazed PVT collectors are more similar to regular PV panels. They consist of a PV-covered absorber with no additional glass cover. The configuration without a glass cover results in lower thermal efficiency compared to the glazed PVT collector. On the other hand, the electrical efficiency of an unglazed PVT collector is higher than that of a glazed PVT collector and is even higher than that of regular PV panels due to the PV cooling effect [3].

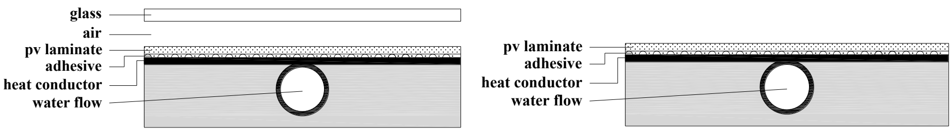

Fig. 1. Sectional view of a water-type PVT collector: (left) glazed type ; (right) unglazed type

Also, water-type PVT collectors can be classified into two types according to absorber type: the sheet-and-tube absorber type and the fully wetted absorber type. The sheet-and-tube absorber consists of pipes and selectively coated plates and is rather common for solar thermal collectors. The fully wetted type has a completely flooded absorber with rectangular fluid channels that increase the heat exchange area. The efficiency of this type of absorber could be better than that of traditional ones. Until now, various designs of water type PVT systems have since been proposed, and the theoretical and experimental performances of PVT systems have been evaluated [4, 5, 6, 7, 8].

The aim of this paper is to analyze the electrical and thermal performance of a water-type unglazed PVT collector with a fully wetted absorber.

2. PVT collector design and experimental method

For this study, a prototype of an unglazed PVT collector with a fully wetted absorber was developed, and both the thermal and electrical performances of the prototype PVT collector were measured in outdoor conditions. A conventional mono-crystalline Si PV module was also tested alongside the PVT collector in order to compare their electrical performances.

The configuration of the unglazed PVT collector with the fully wetted absorber is shown in Fig.2. The PVT collector consists of a PV module and fully wetted heat exchange units made of aluminum plates. The aluminum channel, a fully wetted absorber, was attached on the backside of the PV module with thermal conduction adhesives. The PVT collector had no additional glass cover, and was thermally protected with 50mm of thermal insulation. The PV module used for the PVT collector was a 240W_p mono-crystalline silicon PV module; its electrical efficiency was 16.5% at STC. The specifications of the PV module are shown in Table 1.

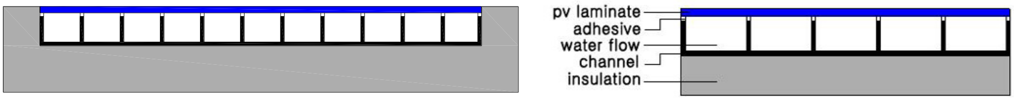

Fig. 2. Sectional view of the unglazed PVT collector with fully wetted absorber

Table 1. PV module specifications

Cell type	Mono crystalline silicon
Maximum power	240W
Maximum voltage	29.93V
Maximum current	8.15A
Shot current	8.56A
Open voltage	37.55V
Size	1656*997*50mm

The PVT collector with fully wetted absorber and the conventional PV module that was used for the PVT collectors were tested under the same outdoor conditions based on ASHRAE Standard 93-2010 [9] and PVT performance measurement guidelines of ECN [10]. The PVT collector with fully wetted absorber was tested at a solar radiation level that exceeded 790 W/m^2 and at a water flow rate of 0.02 kg/sm^2. The electrical and thermal performance measurements were carried out under a quasi-stationary condition in an outdoor environment at the same time (Fig. 3). Several experimental devices were installed to measure the data related to the thermal and electrical performance of the PVT collector.

The PVT collector was also tested at steady state conditions to determine their electrical and thermal performance for various inlets operating temperature. Inlet and outlet water temperature of the collector were monitored and measured using a RTD-type thermocouple with a measurement error of ±0.1% at 0 $^{\circ}$C. The inlet water temperature of the collector was controlled by set temperature equipment and the inlet temperature remained constant, while an outlet temperature varied. Also, the ambient temperature was measured by a T-type thermocouple with measurement error of ±0.2 $^{\circ}$C. Anti-freezing liquid was supplied to the PVT collector at a uniform flow rate of 0.02 kg/sm^2 from a pump. The mass flow rate at inlet pipe of the PVT collector was measured by an electronic flow meter. The normal quantity of solar radiation on the PVT collector surface was measured by an Epply pyranometer installed parallel to the collector plane. Electrical loading resistors and a power meter were used to measure the electrical performance of the PVT collector. All of data related to the thermal and electrical performance of the PVT collector were monitored and recorded at 10s intervals through a data acquisition system.

Fig. 3. (left) Experimental view of the PVT collector and PV module; (right) measuring equipment

3. Results and discussion

With the results of the outdoor test of the PVT collectors, the thermal and electrical performances were analyzed.

3.1. Thermal performance

The thermal efficiency is determined as a function of the solar radiation (G), the mean fluid temperature (T_m) and the ambient temperature (T_a). The steady state efficiency is calculated by the following equation:

$$\eta_{th} = \dot{m}\, C_p\, (T_o - T_i)/(A_{pvt}\, G) \tag{1}$$

η_{th}	thermal efficiency [-]
A_{pvt}	collector area [m^2]
T_o	collector outlet water temperature [$^\circ$C]
T_i	collector inlet water temperature [$^\circ$C]
$\dot{m}$	mass flow rate [kg/s]
C_p	specific heat [J/kg K]
G	irradiance on the collector surface [W/m^2]

The thermal efficiency of the PVT collectors was conventionally calculated as a function of the ratio $\Delta T/G$, where $\Delta T = T_m - T_a$. Here, T_m and T_a are the PVT collector's mean fluid temperature and the ambient temperature, respectively, and G is the solar radiation on the collector surface. Hence, ΔT denotes the measurement of the temperature difference between the collector and its surroundings relative to the solar radiation. The thermal efficiency, η_{th}, is expressed as

$$\eta_{th} = \eta_o - \alpha_1(\Delta T/G) \tag{2}$$

where η_o is the thermal efficiency at zero reduced temperature, and α_1 is the heat loss coefficient.

From the measurement results for the unglazed PVT collector, it can be seen that the thermal performance can be expressed as in Fig. 4. The thermal efficiencies of the PVT collector can be expressed with the relational expression $\eta_{th} = 0.70\text{-}13.29(\Delta T/G)$. Thus, the collector's thermal efficiency (η_0) at zero reduced temperature is 70%, which indicates relatively higher performance; however, the heat loss coefficient (α_1), which can have an effect on reduction of thermal efficiency, is -13.29 W/m^{2}K. The average thermal efficiency of the PVT collector is about 51% under outdoor test conditions and with the given X axis coefficients ($\Delta T/G$).

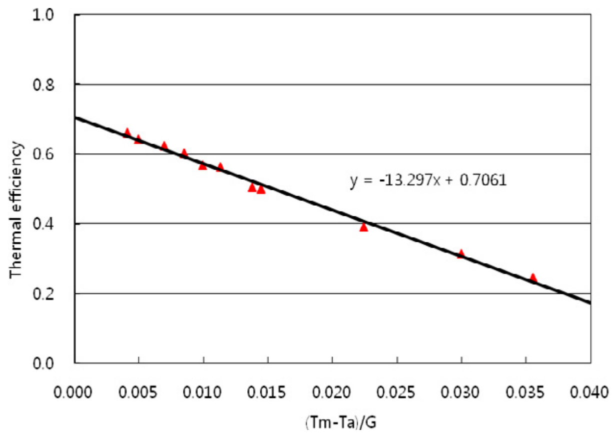

Fig. 4. Thermal efficiency of the unglazed PVT collector with a fully wetted absorber

In order to compare the thermal performance of the fully-wetted PVT collector with that of conventional solar thermal collectors, Fig. 5 presents their thermal efficiencies in relation to $\Delta T/G$. The thermal efficiencies of conventional solar collectors, such as the glazed with black absorber, the glazed with selective absorber, the unglazed solar collector and the evacuated tube type are included [11], along with the experimental result of the fully wetted PVT collector. It was found that the thermal performance of the PVT collector is similar to that of the unglazed solar thermal collector. From this figure, it is also obvious that the thermal performance of the PVT collector is relatively poor compared to the other collectors, since the front plate of the PVT collector consisting of PV module with solar absorber loss more heat and solar radiation reaches indirectly on the absorber.

The unglazed types of PVT collector consisting of a PV-covered absorber without any additional glass cover can have better electrical performance than glazed PVT collectors, as they can receive more solar radiation and release more heat from the PV modules. The electrical efficiency of an unglazed PVT collector is even higher than that of regular PV panels due to the cooling effect of PV module [12].

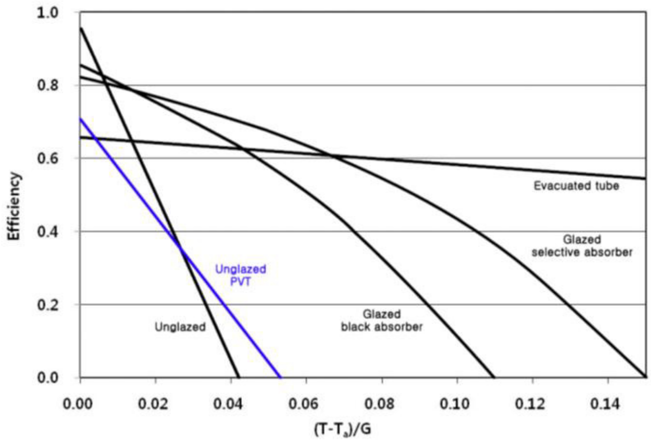

Fig. 5. Thermal efficiency of the unglazed PVT with a fully wetted absorber and other solar thermal collectors

3.2. Electrical performance

The electrical efficiency depends mainly on the incoming solar radiation and the PV module temperature. It is calculated with the following equation:

$$\eta_{el} = I_m V_m / A_{pvt} G \tag{3}$$

Here, I_m and V_m are the current and the voltage of the PV module operating under a maximum power.

The electrical efficiency of the PVT collector depends on the fluid temperature, which can directly affect the PV module temperature; the electrical power is high under the condition of lower fluid temperature. The experimental results show that the electrical efficiency of the PVT collector decreased according to the increase of the fluid temperature, from 10℃ to 40℃, under the same test conditions (Fig 6). The average electrical efficiencies of the PVT collector and the PV module are 14.3% and 12.6%, respectively, and their difference reaches a maximum of 2.4% and has an average of 1.7%.

From these experimental results, it was found that the electrical efficiency of the PVT collector with a fully wetted absorber depends on the temperature of the fluid that flows into the absorber; the collector's electrical efficiency is very sensitive to the temperature, especially compared to the performance of a PV module alone. In particular, it is obvious that the PVT collector had better electrical performance than that of the stand-alone PV module under the same test conditions. These facts indicate that the electrical performance of the PVT collector might have been improved by the cooling effect of the PV modules with the fully wetted absorber.

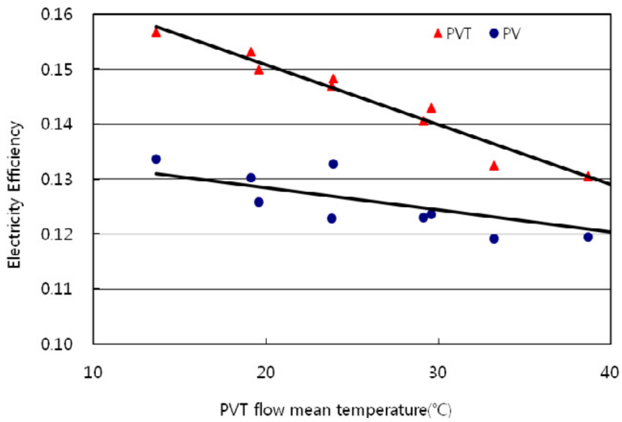

Fig. 6. Electrical efficiency of the fully wetted PVT collector and a PV module

4. Conclusion

This paper analyzed the experimental electrical and thermal performance of the unglazed PVT collector with a fully wetted absorber. For the fully wetted PVT collector, the thermal efficiency at zero reduced temperature turned to be relatively high in comparison with conventional solar thermal collectors, except evacuated tube collector. However, the heat loss of the PVT collector, which can have an adverse effect on the collector thermal efficiency, was greater than others, as the unglazed configuration of the PVT collector without a glass cover seems to lose more heat from the front plate of a PV module with the absorber.

The fully wetted PVT collector had the overall energy performance of about 65%, combining the average values of its thermal and electrical efficiencies. It was concluded that while the PV module installed to be exposed to the outside air generated only the electricity with about 12% efficiency, the fully wetted PVT collector performs better in electricity generation and produces additional thermal energy at the same time.

Also, it is clear that the electrical performance of PVT collectors depends on the cooling effect of the PV module by the fluid. Additionally, the electrical efficiency of the fully wetted PVT collector was, on average, approximately 2% higher than that of the PV module alone. Therefore, the electrical performance of PVT collector was improved by 15% with the cooling effect of PV modules.

Acknowledgements

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